CE Workgroup

Status of Embedded Linux

June 2023

Tim Bird

Principal Software Engineer, Sony Electronics

Nature of this talk…

- I periodically take a look at the status of embedded Linux
  - Not comprehensive – just stuff I saw
  - I'm sorry if I missed something you're working on
- Hope to accomplish 2 things:
  - Let people know what's going on
  - Open a discussion on 'what's next' (and what needs more work)
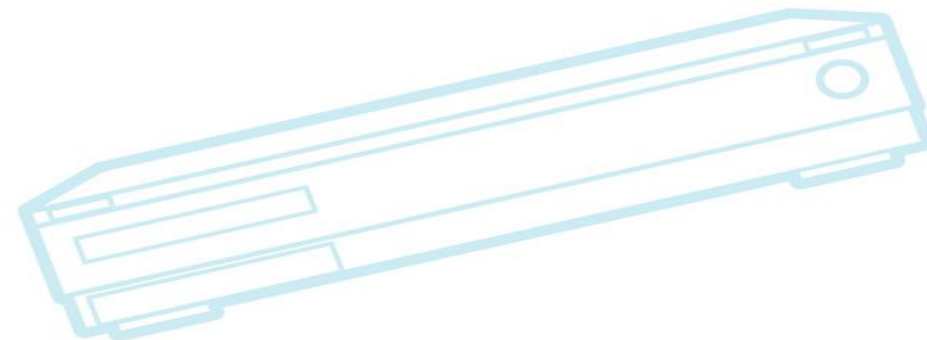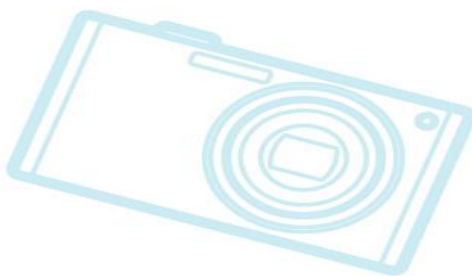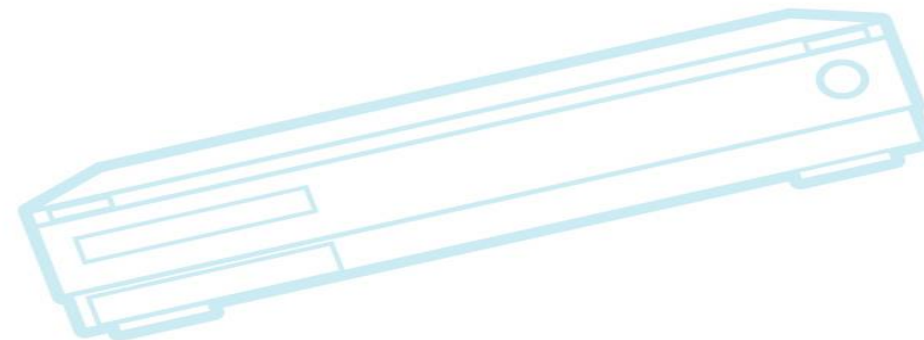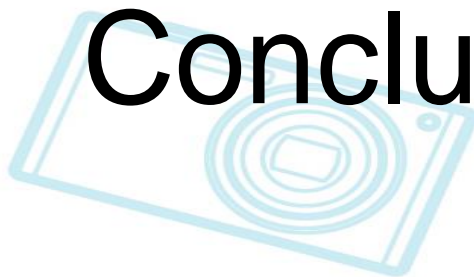
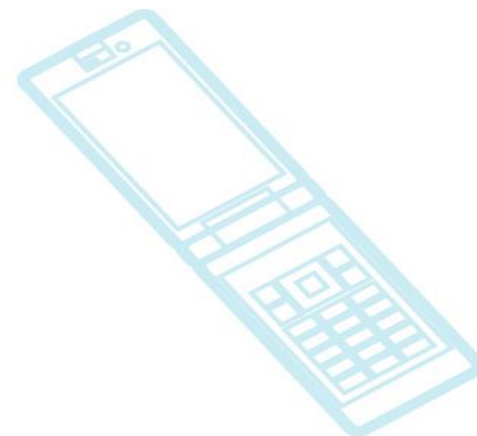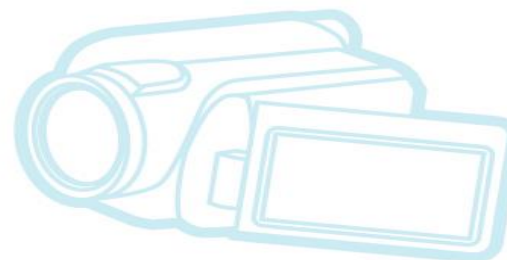# Historical Embedded Linux Focus areas

- System size
- Boot time
- Power management
- Realtime
- Security
- Audio drivers
- Video Drivers
- Flash filesystems (MTD)
- Support for processors, SOCs and boards
  - Arch support and drivers

Outline

Linux Kernel
Technology Areas
Industry News
Community
Conclusions

Outline
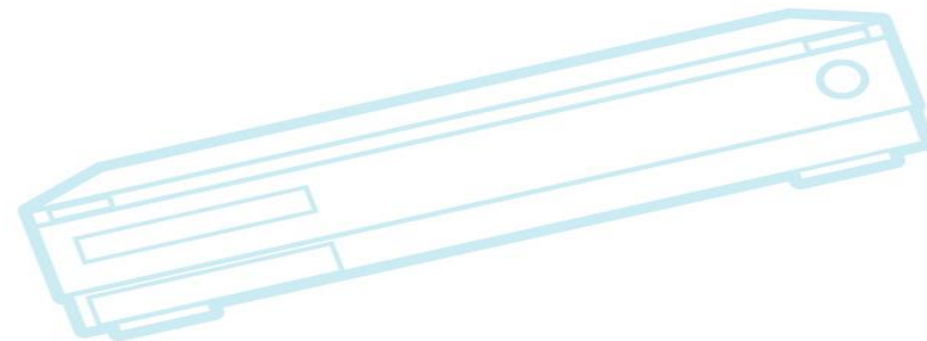
Linux Kernel

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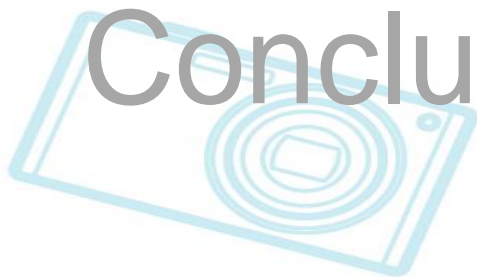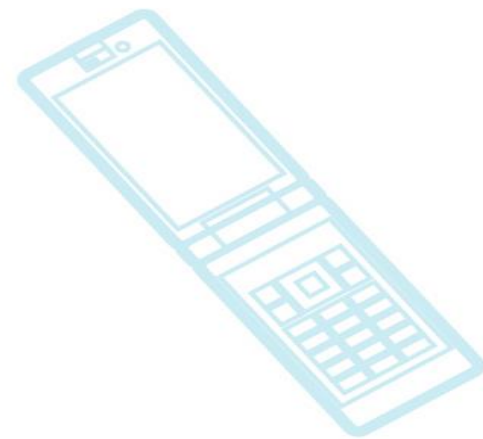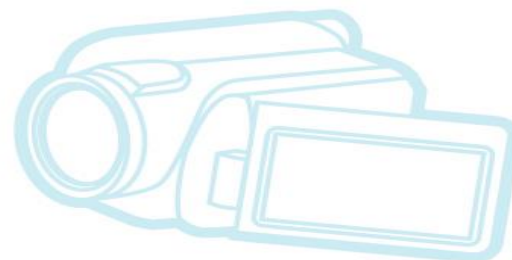
Linux Kernel

- Versions in the last year
  - Pick a few items from each release that are relevant to embedded
    - Lots of things in each release are NOT relevant to embedded (IMHO)
  - Not very good coverage of SoC or driver contributions
- Development Stats
- Some company highlights

Kernel Versions

- Linux v5.19 –   31 Jul 2022   – 70 days
- Linux v6.0   –   2 Oct 2022   – 63 days
- Linux v6.1   –   11 Dec 2022 – 70 days
- Linux v6.2   –   19 Feb 2023 – 70 days
- Linux v6.3   –   23 Apr 2023   – 63 days
- Linux v6.4   –   25 Jun 2023   – 63 days
- We're in the 6.5 merge window this week and next

Linux v5.19 (July 2022)

- Support for a.out executable format removed
  - Was deprecated in 5.1
- EROFS read-only filesystem now uses the fscache layer
  - Gives better performance on some systems
- More packet-drop annotations
  - See https://lwn.net/Articles/885729/
- Can now embed a 'bootconfig' file directly into the kernel image
- Initial support for the LoongArch CPU architecture
  - See Documentation/loongarch/introduction.rst

bootconfig

- Allows passing arguments to kernel as structured key/value pairs
- bootconfig uses a simple text file syntax
- Can be attached to an initrd image, or embedded in the kernel image
- This is useful for passing a large number of tracing options, which would normally make the boot command line too long and complex:
  - e.g. ftrace options, events, filters, actions, probes, fields, etc.
  - Can set up kernel boot-time tracing more easily
- See https://docs.kernel.org/admin-guide/bootconfig.html

Linux v6.0   (October 2022)

- io_uring supports zero-copy network transmission
  - See https://lwn.net/Articles/879724/
- Running Kunit tests now taint the kernel
- Runtime verification system was merged
  - See https://lwn.net/Articles/857862/
- CONFIG_ANDROID config option removed
  - See https://lwn.net/Articles/899743/
- printk pull request was rejected this time
  - Developers have been trying to refactor printk for a while now (for RT and other reasons)
  - Back to the drawing board...

Linux v6.1   (December 2022)

- Support for destructive BPF programs
  - Allows a BPF program to crash the kernel (and create a crash dump)
  - See https://lwn.net/Articles/901284/
- Experimental support for Rust added
- Improved top-level page for kernel's Documentation
- Support for multi-generational LRU
  - Collects pages into groups by age
  - See https://lwn.net/Articles/894859/

Linux v6.2   (February 2023)

- SLOB allocator was deprecated, and the plan is to remove it soon
  - More on this later
- More Rust infrastructure code was added
- Improvements to Squashfs
- New 'rv' tool added to control operation of the runtime verification subsystem

Linux v6.3   (April 2023)

- Lots of old unused Arm board files were removed
- Kernel can be configured with a built-in Dhrystone test
- Default "make V=0" option has been removed
- Minor change to Developer's Certificate of Origin clarifies that nicknames can be used for contributions
  - As long as your identity is known
  - See https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/commit/?id=d4563201f33a

Linux v6.4   (June 2023)

- The SLOB memory allocator was removed
- Some nice documentation added for building the kernel
  - https://docs.kernel.org/admin-guide/quickly-build-trimmed-linux.html
- MODULE_LICENSE() declarations were removed, for code that cannot be built as a module
  - See https://lwn.net/Articles/927569/
- User trace events (API fixes) was merged
  - See https://lwn.net/Articles/927595/

LoongArch

- LoongArch is a processor architecture by Chinese company Loongson
- Architecture started in 2002 as a variant of MIPS
  - LoongArch ISA first released in 2021 (so it's new)
- Incorporates ideas from both MIPS and RISC-V
  - Is not binary compatible with either
- Supports 32-bit reduced instruction set, 32-bit standard, and 64-bit instruction sets
- Linux seems to be the primary OS target supported by LoongArch
- See https://en.wikipedia.org/wiki/Loongson

Linux 6.3 developer stats

- 14,424 change sets, by 1971 developers (250 new devs.)
- Most active 6.3 developers, by changesets:

Person	Org.	Changesets	Percent	Subsystem Area
Krzysztof Kozlowski	Linaro	387	2.7%	device tree updates
Dmitry Baryshkov	Linaro	317	2.2%	Qualcomm device drivers
Arnd Bergmann	Linaro	185	1.3%	Removal of old arch and device driver code
Andy Shevchenko	Intel	175	1.2%	Cleanup in the driver tree
Christoph Hellwig	?	167	1.2%	Refactor block and filesystem code

Table data:
https://lwn.net/Articles/929582/

Linux 6.3 developer stats

- Most active 6.3 developers
- By lines of code changed:

Person	Org,	Lines changed	Percent	Subsystem area
Arnd Bergmann	Linaro	160437	16.4%	Removal of old code
Kalle Valo	Qualcomm	53435	5.5%	Qualcomm WiFi driver
Greg Kroah-Hartman	Linux Foundation	52609	5.4%	Lots of device driver work, removed r8188eu driver from staging
Hans Verkuil	Cisco	28249	2.9%	Removed old media drivers
Cai Huoqing	?	19975	2.0%	Removed lots of DRM drivers

- 4 out of 5 developers made the "top changes" list by removing code!

Table data:
https://lwn.net/Articles/915435/

Kernel commit log entries

- Number of commit log entries (including merges), per kernel version

Company	git log count	developer count
5.19	16399	2170
6.0	16584	2111
6.1	15109	2117
6.2	16840	2167
6.3	15637	2052
6.4	16011	2076

- Extracted using 'git log v6.yy..v6.zz –oneline | wc –l' and 'author-stats v6.yy..v6.zz | wc –l'

Most-Active Organizations, by Subsystem

- Here are the most-active organizations, by kernel area:

Kernel Area	Organizations with over 5% total contributions from 5.18 to 6.3 (approx. 1 year)
Core kernel	Google, Oracle, Huawei, Red Hat, Meta, Intel
Arch	Linaro, Google, IBM, (Unknown), Intel
Drivers	Intel, AMD, (Unknown), Linaro, (None)
Filesystem & block layer	Red Hat, SUSE, Oracle, Meta, Huawei, (Consultant)
Networking	Intel, Red Hat, Google, Meta, (Unknown), NVIDIA
Documentation	(Unknown), (None), Google, Intel, Red Hat, Meta, Loongson

Table data:
https://lwn.net/Articles/915435/

Contributions by embedded Linux companies (to kernel)

Company	company commits since July 2022	Top contributor	Work area(s) (of top contributor)
Baylibre	216	Corentin Labbe	rockchip, crypto
Bootlin	356	Miguel Raynal	network, mtd spi-nor, nvmem
Collabora	757	AngeloGioacchino Del Regno	mediatek processor support
Ideas On Board	485	Laurent Pinchart	camera, media drivers
Igalia	103	Guilherme G. Piccoli	drm AMD GPU driver, pstore
Konsulko	6	Matt Ranostay	USB to I2c driver fixups
Linutronix	346	Thomas Gleixner	timers, x86, preempt_rt
Pengutronix	1980	Uwe Kleine-König	i2c, iio, leds, driver cleanups, mtd
Toradex	199	Marcel Ziswiler	dts work on ARM platforms
Wind River	22	Paul Gortmaker	powerpc cleanups

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Linux Kernel

Technology Areas

Industry News

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Technology Areas

- Architectures
- Bootloaders
- Core Kernel
- Filesystems
- Languages
- Networking
- Security

- Testing
- Tools
- Toolchains
- Tracing
- System Size
- Build Tools and Distros

Architectures

- LoongArch support recently added (v5.19 and 6.x kernels)
- Support for many old ARM boards was recently removed
- Proposed removal of old Architectures
  - Super-H
  - Itanium
- Community discussion: How long to keep code in kernel?
  - Answer seems to be: as long as it doesn't impose a burden on maintainers for other areas
  - Or, someone cares about latest kernel enough to maintain it
- See https://lwn.net/Articles/920259/

Bootloaders

- ## U-Boot
  - Now supports loading images over HTTP
    - Previously only supported the UDP protocol
    - Could only use NFS or TFTP as servers
    - Now can download kernel and other images (dtb, initrd, etc.) from a web server
    - See https://www.linaro.org/blog/http-now-supported-in-u-boot/
- ## Snagboot
  - See next page

snagboot

- Snagboot is a set of tools that can help boot and install images on boards that fail to boot
- Produced by Bootlin
- Consists of
  - snagrecover – to initialize memory and run your bootloader
  - snagflash – to flash a working system image using either DFU, USB Mass Storage, or fastboot
- Works on several different boards, and replaces proprietary tools
- See https://bootlin.com/blog/releasing-snagboot-a-cross-vendor-recovery-tool-for-embedded-platforms/

Core Kernel

- Work being done on io_uring_spawn
  - Is more efficient than traditional user-space based 'fork & exec'
    - fork & exec almost always discards the parent's code immediately
  - Can do IORING_OP_CLONE followed by IORING_OP_EXEC
    - All inside the kernel, without interaction with user space
  - 6-10% faster than vfork() and 30+% faster than posix_spawn()
  - See https://lwn.net/Articles/908268/

Filesystems and I/O

- Some work on MTD spi-nor
  - Enhanced locking to support reads while writing
- EROFS enhancements
  - caching and speed improvements
- Lots of tweaks to existing filesystems and drivers
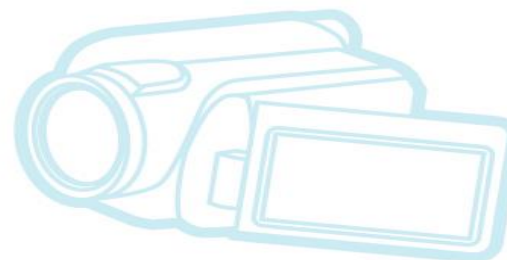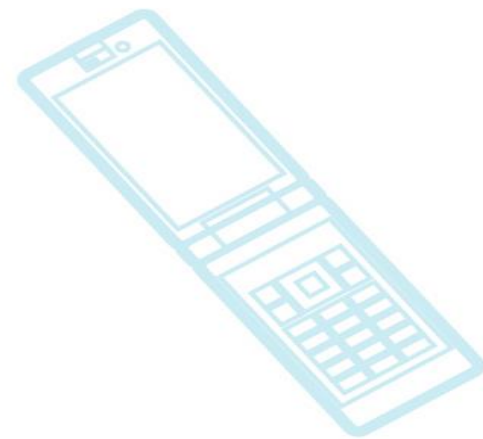 - Not much specific to embedded
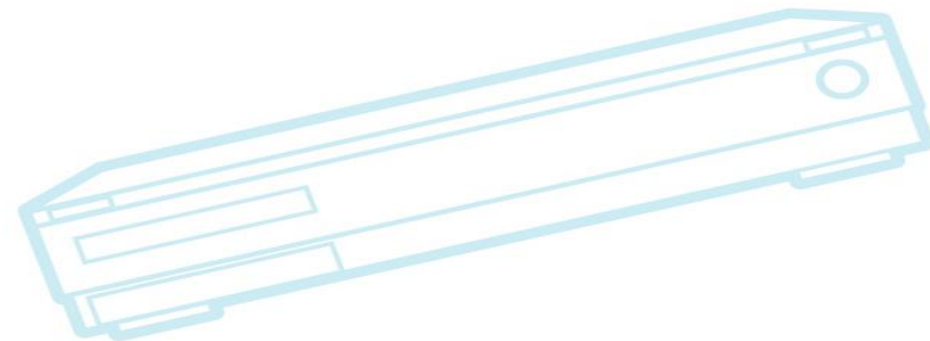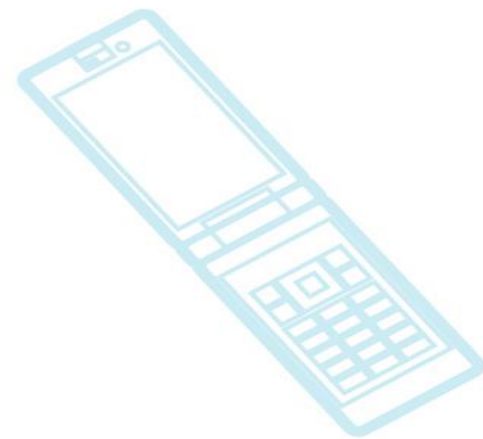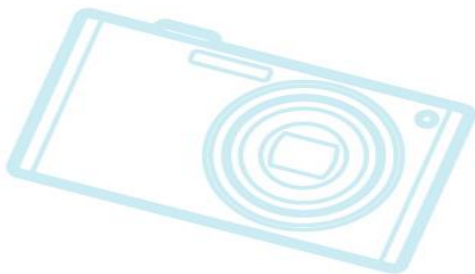
Languages

- Micro-Python
- Python
- Rust
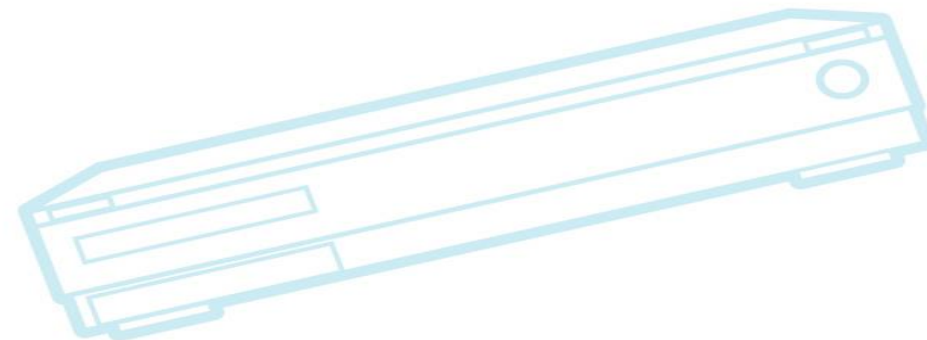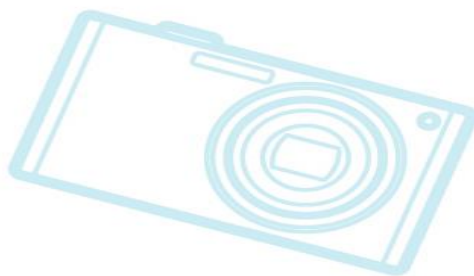
Micro-Python

- Version of python specifically targeted at microcontrollers and embedded use cases
- Version 1.2 released in April, 2023
- New Features:
  - New package manager (mip) can install packages from the micropython-lib repository
  - Reduced code size
    - Developers can pre-compile modules
  - Add support for many new boards
    - Support for Zephyr
    - Can target WASM (web assembly), to run in Python apps in browsers
- See https://lwn.net/Articles/931051/

Python

- Python 3.11.3 released in April, 2023
- Python 3.11 has a lot of improvements
  - Better tracebacks
    - Fine-graied error locations in tracebacks
  - Faster (!!)
    - Claims a 1.22x speedup on the standard benchmark suite
    - Up to 10-60% faster than Python 3.10
  - Exception groups and except*
  - Typing improvements
  - See https://discuss.python.org/t/python-3-11-0-final-is-now-available/20291

Python programs debugged using AI

- "Wolverine" project debugs Python programs using AI
- Wolverine runs the program, and performs "automatic healing"
- When a crash is detected, it uses GPT-4 to:
  - Analyze the failure
  - Generate and apply a bugfix
  - Re-run the program, to continue to detect problems
- See https://arstechnica.com/information-technology/2023/04/developer-creates-self-healing-programs-that-fix-themselves-thanks-to-gpt-4/

Rust

- Rust support continues to go into the mainline kernel
  - But it has not been used for a "real" driver yet
- My own impression:
  - Rust is being used more and more throughout the industry
    - ex: KataOS = secure operating system written by Google
    - See https://www.phoronix.com/news/Google-KataOS
- Rust 1.71 will likely support the musl C library
- Google announces their results analyzing Rust crates
  - See https://opensource.googleblog.com/2023/05/open-sourcing-our-rust-crate-audits.html

Networking

- New function to provide reason for a packet drop (5.17)
  - Kfree_sdk_reason() function
    - `void kfree_skb_reason(struct sk_buff *skb, enum skb_drop_reason reason)`
  - Helps administrators determine reason for networking issues
  - Only 63 of 4000 kfree_skb() calls converted as of 5.17 (when introduced)
  - More instrumentation has been done over the last year
    - About 220 sites instrumented now
      - grep SKB_DROP_REASON | grep –v dropreason-core.h | wc -l
  - See https://lwn.net/Articles/885729/

Real-Time

- PREEMPT_RT status
  - Sleeping locks was mainlined (v5.16)
  - Patches have been going in continuously – through 6.4
    - Although some stalled (like the printk refactor)

PREEMPT_RT - What's left

- What's left in PREEMPT_RT patches out of mainline:
  - last year (2022):
    - About 1300 lines of code, affecting 92 files (in 51 patches) (!!)
  - this year (2023) (patches-6.4-rc5-rt4):
    - About 3100 lines of code, affecting 93 files (in 85 patches)
      - Number of lines could be off due to printk work-in-progress
    - Some changes to the printk, 8250 serial driver, the core scheduler, some locking and timer tweaks, and a few other places.
  - People are still anxious for Linux RT without having to apply a patch
    - Thomas said on Monday that printk changes are the blocker to the patch that allows enabling PREEMPT_RT in the mainline (Torvalds) kernel
- See https://mirrors.edge.kernel.org/pub/linux/kernel/projects/rt/6.4/

Security

- Kernel hardening continues
- BPF raises some interesting security issues (unsurprisingly)
  - Authoritative LSM hooks (ones that can override other security mechanisms) was proposed for BPF, but rejected
  - There has been some discussion about allowing unprivileged users to run BPF modules
    - Not sure if anything will happen there
  - See https://lwn.net/Articles/929746/

System Size

- SLOB memory allocator removed from kernel (v6.4)
  - Not enough people using it (or reporting that they use it)
  - Was deprecated in v6.2
    - IMHO, 2 releases (5 months) isn't enough time for people to notice the deprecation and object to it
  - Don't move to SLAB, as that's planned for deprecation also
  - Instead, move to SLUB, and use CONFIG_SLUB_TINY
- Bloaty McBloatface size profiler tool
  - Tool by Google to analyze size of binary images
  - Does deep inspection of ELF binaries
  - Can show comparison between two binaries
  - See https://github.com/google/bloaty
  - Was open-sourced in 2016 and I just found it this year!

nolibc
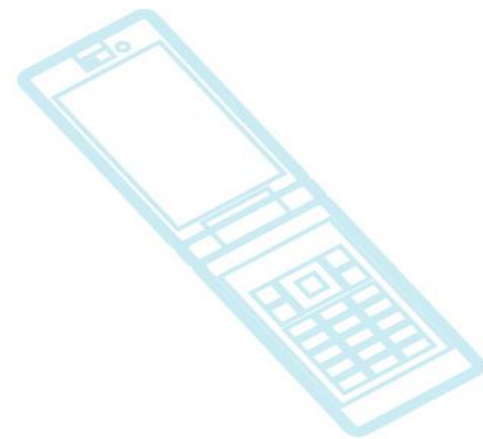
- Is a minimal C-library replacement shipped with the kernel
  - Originally created for kernel testing
  - Consists of a set of .h files, which create macros to replace common C library functions
- Allows creation of a very small static binary
  - For some binaries, the statically linked binary using nolibc is smaller than the binary using libc (using dynamic libraries)
    - e.g. hello-libc size=1159 bytes, hello-nolibc = 1100 bytes
- Lots of issues to look out for, but an interesting approach to create minimal binaries in Linux
- See https://lwn.net/Articles/920158/

Testing

- Systems
- Suites of tests
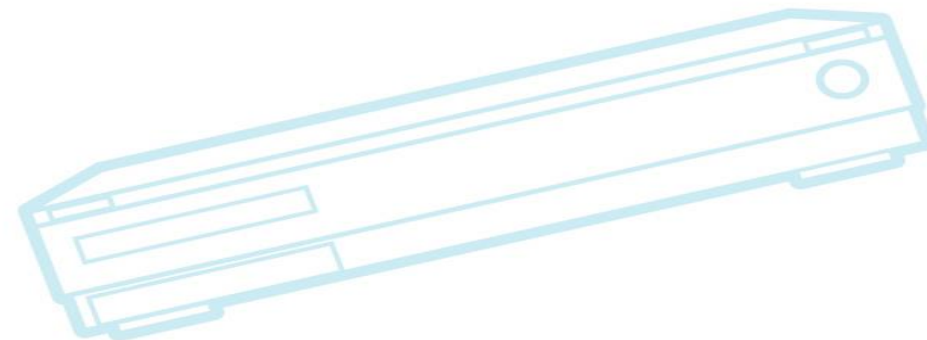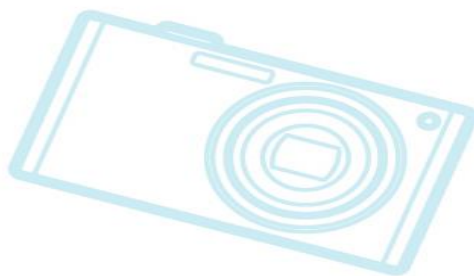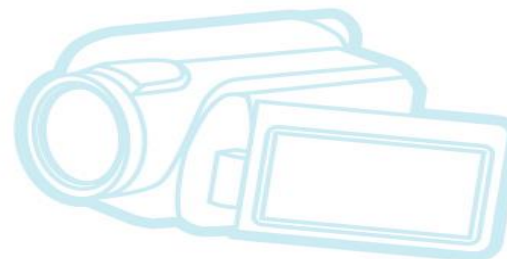
Test Systems

- 0-Day – reports bugs at time of patch submission
- KernelCI – has added kselftest git repo to list of trees it tests
- Syzbot – always producing more fuzzing failure cases
- CKI – providing reports to upstream
- LKFT – providing reports to upstream

Test Suites

- LTP
  - Latest release: 20230516 (May 27, 2022)
    - New test and fixes to tests
    - Added new "runltp-ng" – test execution manager
      - Can execute tests on a separate machine
    - See https://github.com/linux-test-project/ltp/releases
- kselftest
  - Lots of tests and test improvements for bpf, mm, resctrl, hid, xsk, networking, x86 features, powerpc, KVM, landlock and more
- Kunit
  - kunit tool improvements

Toolchains - GCC

- GCC 13.1 released April 26, 2023
  - See https://gcc.gnu.org/gcc-13/changes.html
  - LTO (link-time optimizations) has been improved
  - Can now emit diagnostics in the SARIF format and gcc's own JSON-based format
    - SARIF = Static Analysis Results Interchange Format
  - Support for C23 features
  - LoongArch support improvements
  - Improvements in the static analyzer

Toolchains - LLVM

- LLVM 16.0.0 released March 17, 2023
  - See https://releases.llvm.org/16.0.0/docs/ReleaseNotes.html

- People are using it for whole distributions, not just kernel
- See presentation: "Experiences of OS distributions using LLVM as their main toolchain"
  - By Bernhard Rosenkranzer at 2022 European LLVM Dev. meeting
  - https://youtu.be/h9xg8Y8byIg

Tools
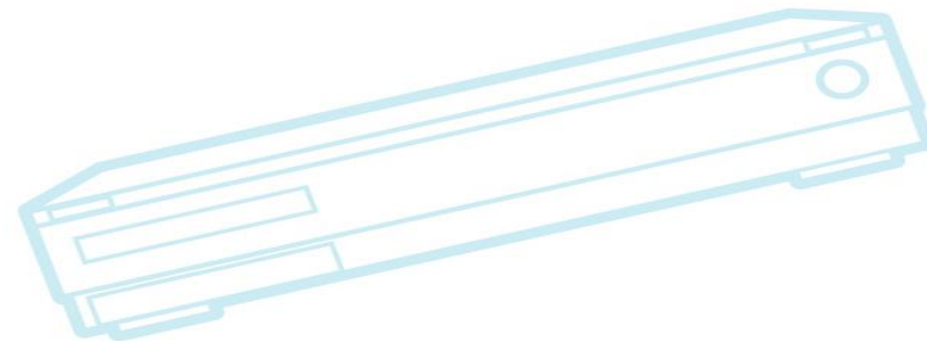
- b4
  - Is a tool for retrieving patches from mailing lists
  - But can also help contributors:
    - Create and manage patch series and cover letters
    - Track and auto-reroll series revisions
    - Display range-diffs between revisions
    - Apply trailers received from reviewers and maintainers
    - Submit patches without needing a valid SMTP gateway
- b4 submission of kernel patches
  - It is now possible to contribute a patch without using email!
  - However, it's a good idea to be subscribed to relevant lists in order to respond to comments
  - See https://people.kernel.org/monsieuricon/sending-a-kernel-patch-with-b4-part-1

Tracing

- Something is always going on with perf
  - New features seem to be added every release
- eBPF is now used for tracing

Build Tools and Distros

- Yocto Project
  - BMW joined Yocto Project
    - See https://www.theregister.com/2022/07/20/yocto_project_4/?td=keepreading
  - Latest version = 4.2 (Mickeldore), released May, 2023
    - Kernel 6.1 and 350+ recipe upgrades
    - Improved memory and disk usage
    - Improved recipe parsing time
    - Now requires Python 3.8
    - Bunch of other changes
    - See release notes:
      - https://docs.yoctoproject.org/next/migration-guides/release-notes-4.2.html

Kernel community

- Linus now uses scripts to check language in his emails
  - When Linus quotes other people's email, sometimes the script catches a word or phrase that Linus did not write
  - Linus has kindly asked that other developers "please don't call each other morons on the mailing lists"
  - See https://lwn.net/Articles/908466/
- Slight change to DCO (Developer Certificate of Origin)
  - Can use "known identity" instead of "real name"
  - Still precludes anonymous contributions, but allows nicknames
  - See https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/commit/?id=d4563201f33a

Outline

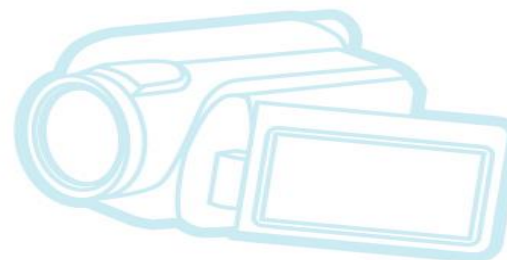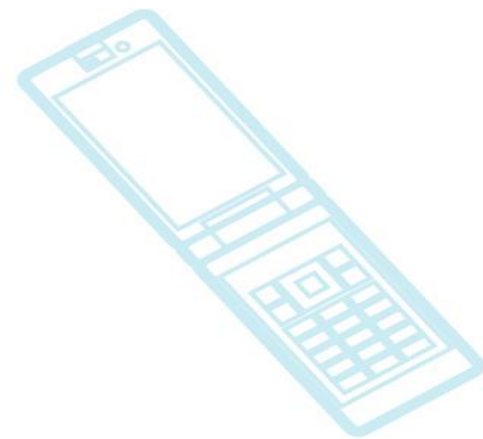Linux Kernel
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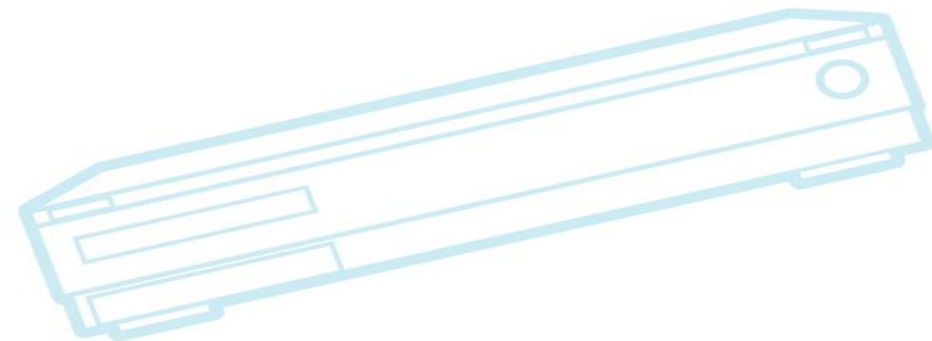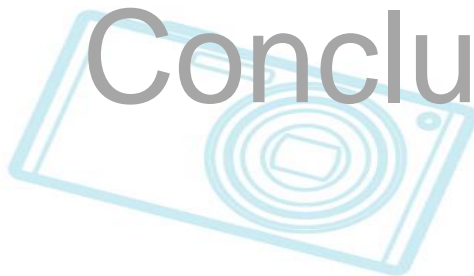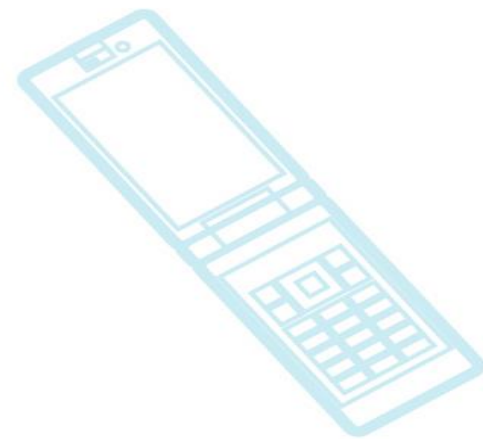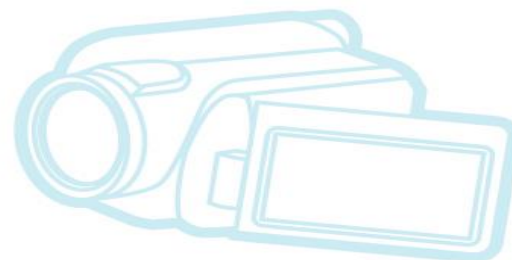
Industry News

- Legal issues
  - SFC sues Microsoft over github co-pilot
- Intel and ARM agreement
- NASA and RISC-V
- Miscellaneous

SFC sues Microsoft over github co-pilot

- SFC alleges that use of GPL code in training data for co-pilot is a GPL violation
  - Argument is that software was used (and redistributed) and that license terms are being violated
  - SFC gave some examples where code produced by co-pilot exactly matched GPL code
- Similar in spirit to other lawsuits for StableDiffusion
- Raises questions about copyright interaction with training data for ML models
- See https://www.theverge.com/2022/11/8/23446821/microsoft-openai-github-copilot-class-action-lawsuit-ai-copyright-violation-training-data

Intel Foundry and ARM agreement

- Intel and ARM announce collaboration on designs using Intel's 18A process
  - I8A is farthest item in a long-term roadmap by Intel for continued shrinking of processor features
  - 18 Angstroms = 1.8 nanometers
- Quote: "By unlocking Arm's leading-edge compute portfolio and world-class IP on Intel process technology, Arm partners will be able to take full advantage of Intel's open system foundry model, which goes beyond traditional wafer fabrication to include packaging, software and chiplets."
- See https://www.intel.com/content/www/us/en/newsroom/news/intel-foundry-arm-announce-multigeneration-collaboration-leading-edge-soc-design.html
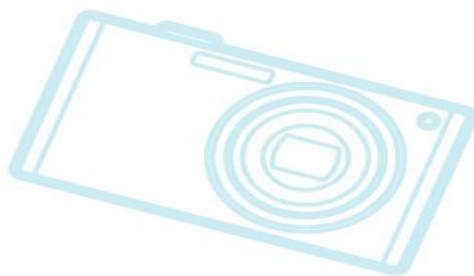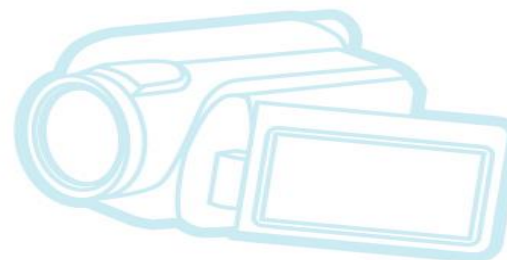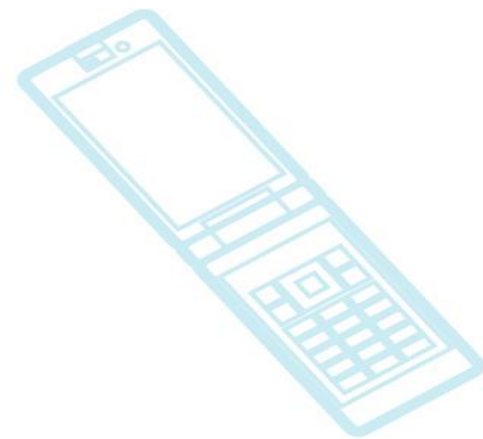
NASA and RISC-V

- NASA JPL (Jet Propulsion Lab) have selected Microchip to design and produce a 12-core RISC-V processor
- For the "High Performance Spaceflight Computer"
- 8 RISC-V cores with vector processing extensions (in 2 clusters) + 4 general purpose RISC-V cores
- Is designed for high performance and fault tolerance
- Maybe be used outside of space applications
- See https://www.eejournal.com/article/nasa-recruits-microchip-sifive-and-risc-v-to-develop-12-core-processor-soc-for-autonomous-space-missions/

Industry News

- Miscelaneous
  - Lennart Poetering has a new job
  - Interesting cases of embedded Linux

Miscelaneous

- Lennar Poetering has a new job
  - Lennart is the author of systemd
  - Left Red Hat, and is now working for Microsoft (as of July 2022)
  - Lennart is still working on systemd
  - Microsoft has hired a number of Open Source and Linux leaders in the last few years
    - MS OSS folks may be associated with Azure, or Windows Subsystem for Linux
  - See https://www.phoronix.com/scan.php?page=news_item&px=Systemd-Creator-Microsoft

Interesting embedded Linux uses

- Satellites
  - CubeSats
 - Starlink satellite constellation
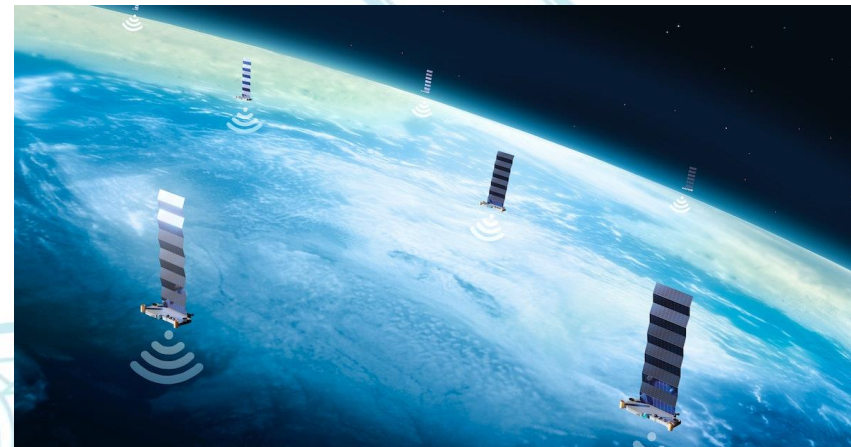- Mars Ingenuity helicopter
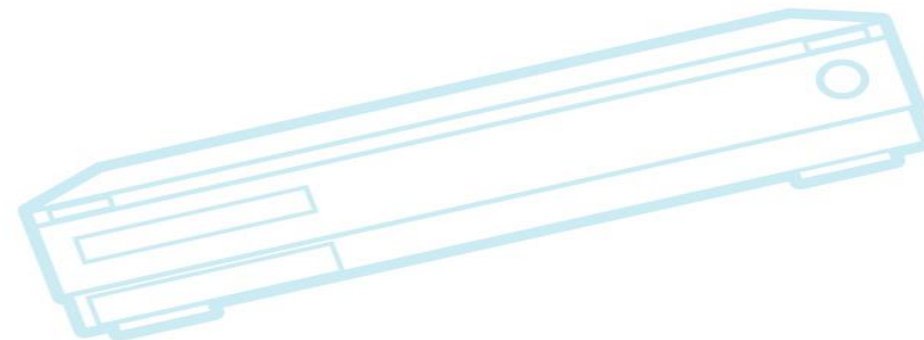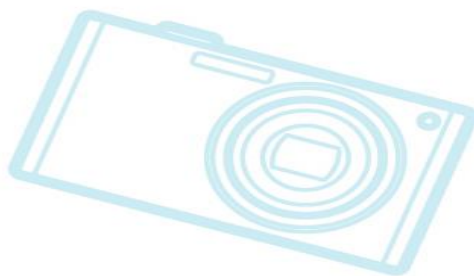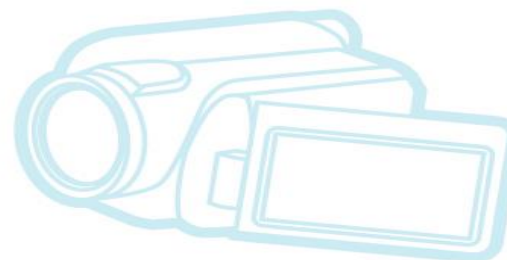
Linux in Satellites

- Linux is currently being used in many satellites
- CubeSats
  - Linux has been used in satellites since 2003
    - Lots of experiments with Linux and COTS in cubesats since 2014
    - One example: NASA PhoneSat (using an Android phone as the flight computer for a cubesat)
  - One estimate is that about 50% of cubesats run Linux (in some part of the flight stack)
- Major constellations (StarLink and Planet) use Linux
  - (see next slide)

Starlink Satellite constellation

- SpaceX uses Linux in their rockets, space capsules and satellites
- Each Starlink satellite uses over 60 processors, each one running Linux
  - Uses clusters for fault tolerance
    - Voting algorithms
    - Sub-component reboot capabilities
    - Redundant failover
- There are now (as of June 2023) over 4600 Starlinks satellites currently in orbit
  - https://satellitemap.space/ is quite interesting!!
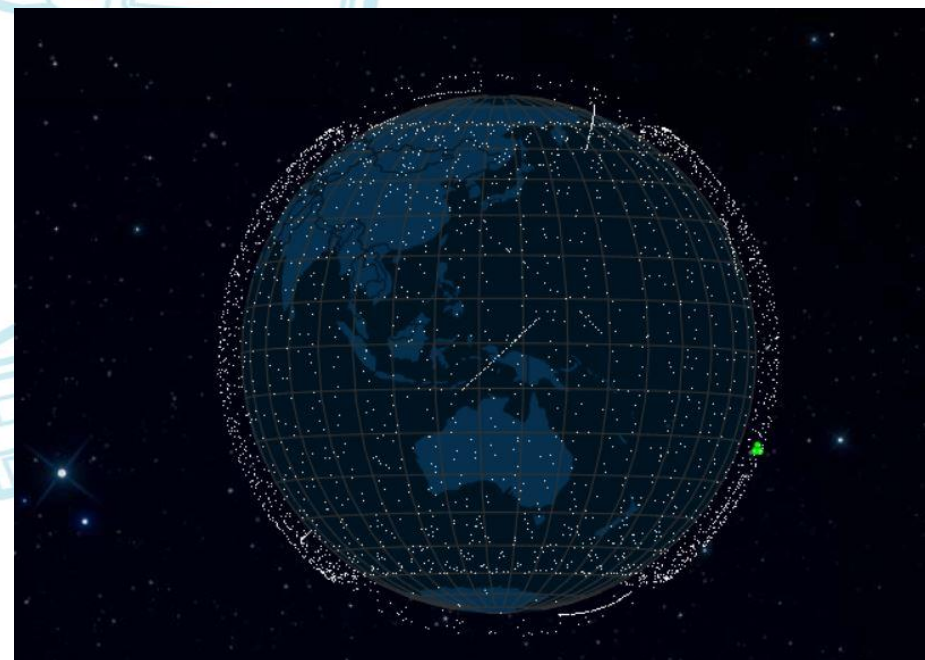
Mars Helicopter - Ingenuity
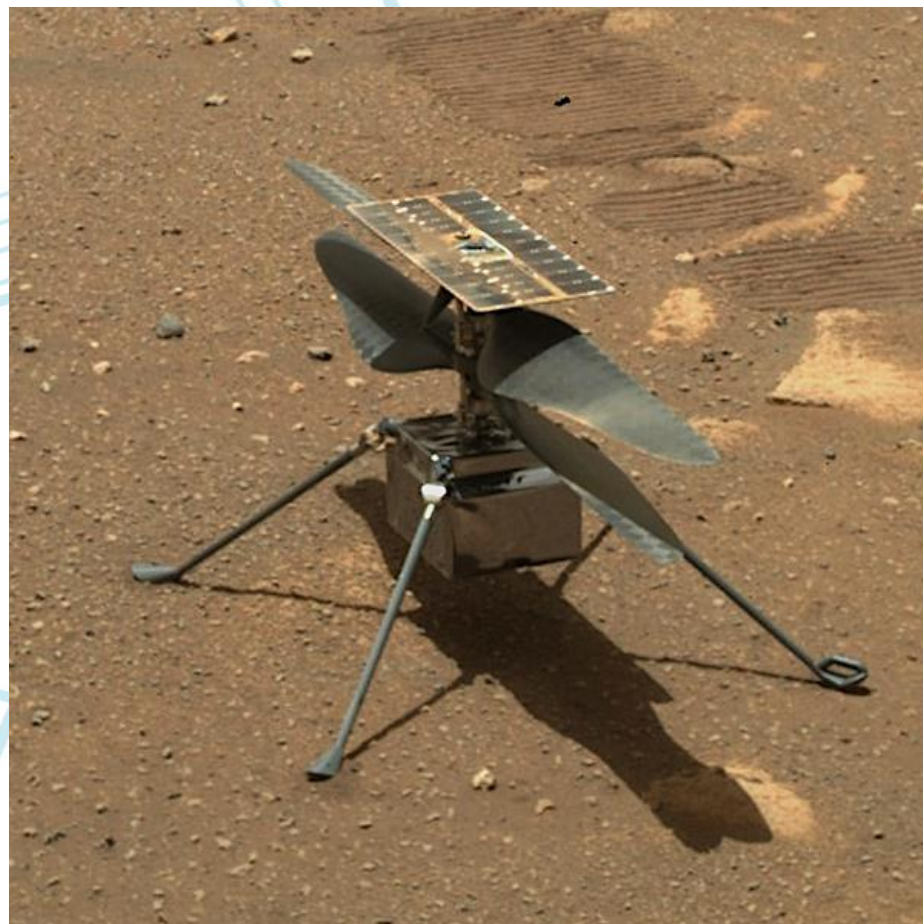
Mars Helicopter

- Mars Ingenuity Helicopter landed in February, 2021 on Mars
- Performed tests and demonstrations in April & May (2021)
  - First 5 flights were part of "Technology Demonstration"
- After demo, NASA created a plan for continued flights
- Is still flying...
  - Has performed 51 flights so far
- Updates:
  - Autonomous landing site selection

Ingenuity Helicopter Update (June 2023)

- Autonomous Landing Site Selection
  - NASA uploaded a new Landing hazard mitigation system
    - First used in flight 39
  - Detects the slope of the landing area, and any debris that might interfere, and adjusts landing position
- Scouting for Perseverance
  - Provides pictures of areas of interest, and potential navigation concerns for the rover Team
  - Now off the crater floor, terrain is more rugged, and helicopter may land somewhere outside of communications range
  - Flights 41-46 consisted of keeping Ingenuity ahead of the rover
    - Canyon was too narrow for Ingenuity to safely pass the rover if it fell behind
- Playing hide and seek
  - Lost radio contact for a few days, causing concerns
    - See https://mars.nasa.gov/technology/helicopter/status/466/hide-and-seek/

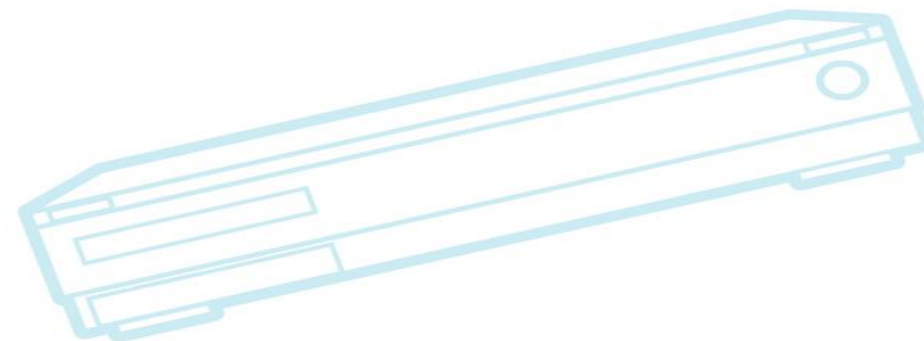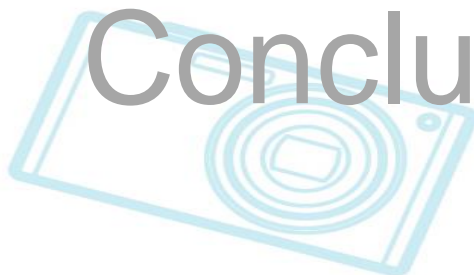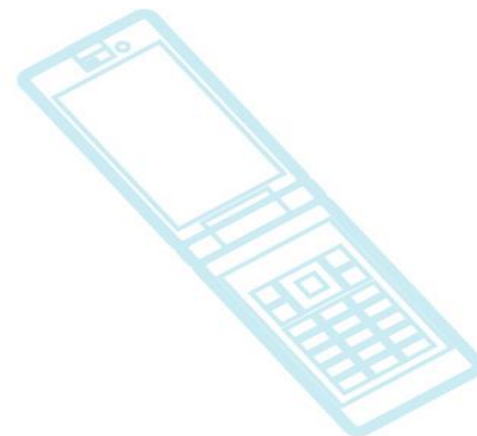# Ingenuity flights on Mars

Sources for Mars helicopter

- Talk by Tim Canham at ELC 2021
  - Slides:https://elinux.org/images/5/5a/1._TIMOTHY_CANHAM.pdf
  - Video: https://youtu.be/0_GfMcBmbCg

- https://mars.nasa.gov/technology/helicopter/
- https://en.wikipedia.org/wiki/Ingenuity_(helicopter)
- https://thenewstack.io/how-the-first-helicopter-on-mars-uses-off-the-shelf-hardware-and-linux/
- https://www.pcmag.com/news/4-android-smartphones-with-as-much-power-as-nasas-mars-helicopter

Outline

Linux Kernel
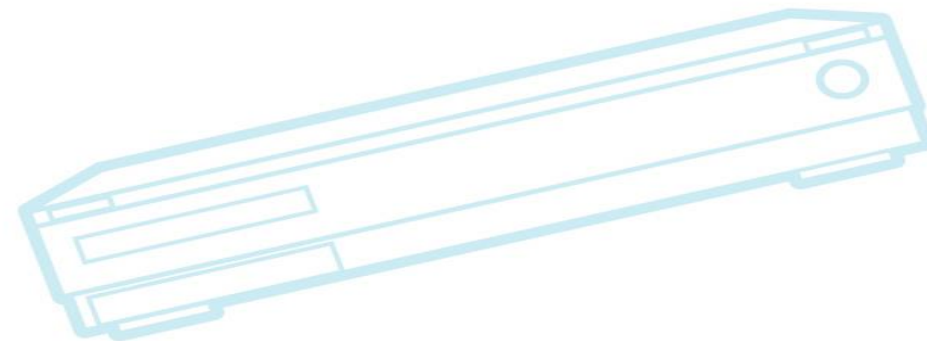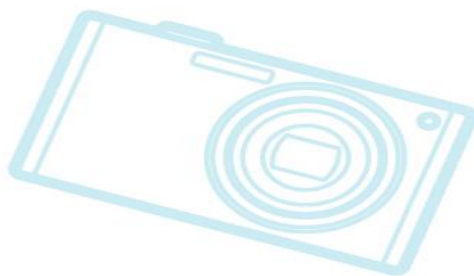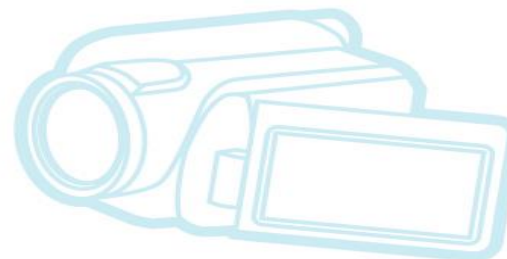Technology Areas
Industry News
Community
Conclusions

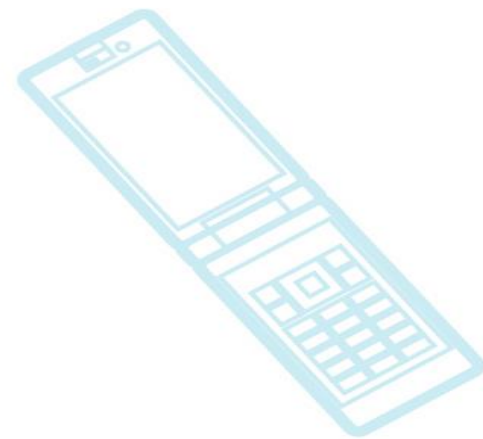# **Community**

- A sad note
- Conferences
- Elinux wiki
- Trade Associations and Projects

A sad note about Wolfgang Denk

- On October 14, 2022, Wolfgang Denk died
- Wolfgang was the founder of Denx Software Engineering
- A pioneer in the field of embedded Linux
  - The creator "Das U-Boot"
    - With a sense of humor
  - Early work in realtime solutions for Linux
- A champion for Open Source
- Wolfgang will be missed

Conferences

- Embedded Linux Conference
  - Is now only once a year
    - Alternates between Europe and North America
    - So, effectively only once per region every two years
    - May decide to fill in with regional events or Plumbers
  - Sometimes in Embedded Open Source Summit, and sometimes in Open Source Summit (North America)
  - Consistently in the spring (April/May)
  - Next one = June 28-30 in Prague, Czech Republic
  - 2024 = April 15-19 in Seattle, USA

Conferences (cont.)

- Japan Jamboree
  - Not sure if there will be more after this one (#80)
- Embedded Recipes
  - September 28-29, 2023 in Paris
- Linux Plumbers
  - Could have an embedded microconference
  - November 13-15, 2023 in Richmond, Virginia, USA
- FOSDEM
  - Has an embedded track
  - February 3,4 2024 (not confirmed) in Brussels

Elinux wiki

- Losing funding for our elinux.org administrator (Bill Traynor)
- Site is still used for:
  - Materials for embedded Linux development boards
  - Some academics use it for coursework
  - Event materials: slides and links to videos for ELC
- Some areas of the site are out-of-date
- I feel like the site is underutilized for sharing information
- What to do next....? (Any volunteers?)

Trade Association and Projects

- Linaro – does ARM upstreaming and projects
  - Still going strong!!
- Robot Operating System (ROS) – handles robotics vertical
- Android Open Source Project (AOSP) – handles mobile phone vertical
  - And there are others (e.g. LineageOS, PinePhone, etc.)
- Yocto Project, Buildroot, OpenWRT– build systems for embedded Linux and routers

Linux Foundation projects

- Linux Foundation
  - Core Infrastructure Project (CIP) – handles support longevity
  - ELISA – handled issues with safety certification and standards
  - OpenChain – handles issues with supply chain
  - SPDX – Deals with licensing issues and SBOMs
  - Automotive Grade Linux (AGL) – handles automotive vertical
  - KernelCI – handles automated testing (for upstream)
  - Yocto Project – build system for embedded OSS (not just Linux)
  - DroneCode – handles drone vertical
  - Core Embedded Linux Project – is shutting down

Automotive Grade Linux (AGL)

- Continued evolution of the Flutter support (by Toyota)
  - Will have improved workspace automation in upcoming Prickly Pike release (16.0.0) planned for July/August release
- Bringing Chromium Embedded Framework (CEF) into AGL for Pike as well.
- Rust mix-layer for Yocto Project
  - Enables the latest Rust version to be used with AGL
  - It was upstreamed to Yocto Project as well.
- Enabled the gRPC version of Vehicle Signal Specification (VSS) KUKSA.val version.
  - Depended on latest RUST availability
  - Enables AGL collaboration with other open source projects
- Check out Walt Miner's talk earlier this week for more info

Core Embedded Linux Project

- History:
  - Started as Consumer Electronics Linux Forum in 2003
  - Migrated to Embedded Linux Workgroup in the LF in 2011
  - Became Core Embedded Linux Project in 2015
- Funded upstreamining of various technologies
  - Linux-tiny patches, squashfs, realtime work, power management features, etc.
- Started the Embedded Linux Conference
- Sponsored the eLinux wiki for many years
- Now, plan to end in July 2023 (after 20 years)

Outline

Linux Kernel
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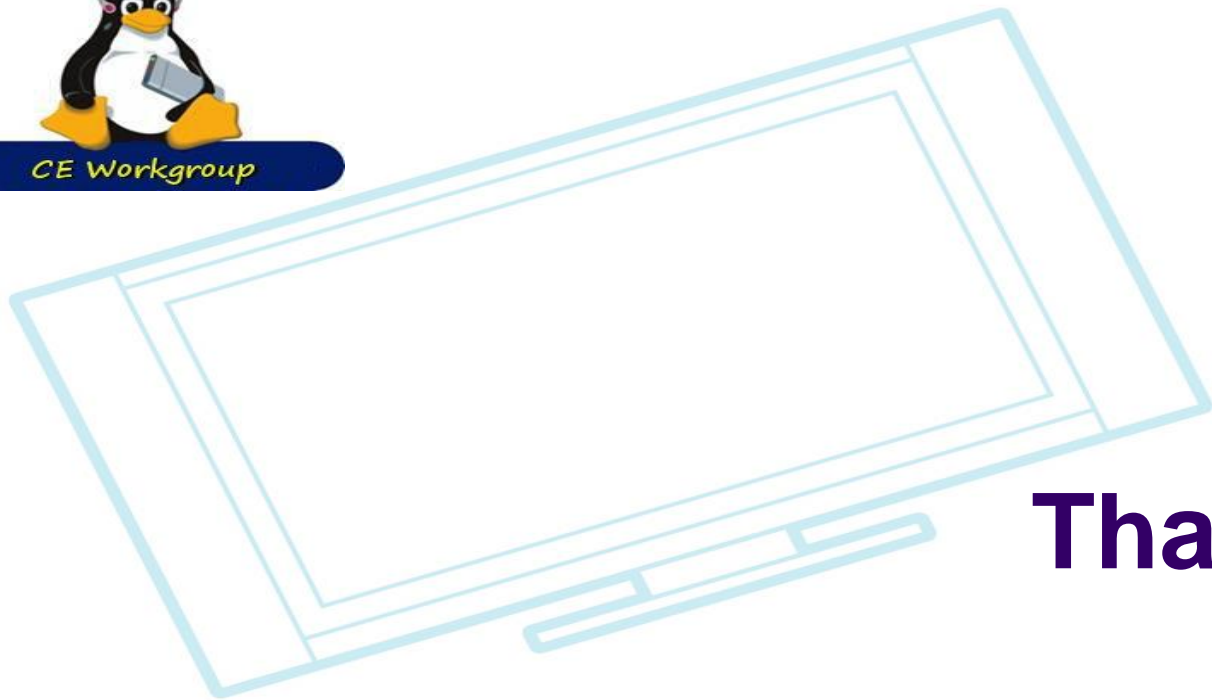Industry News
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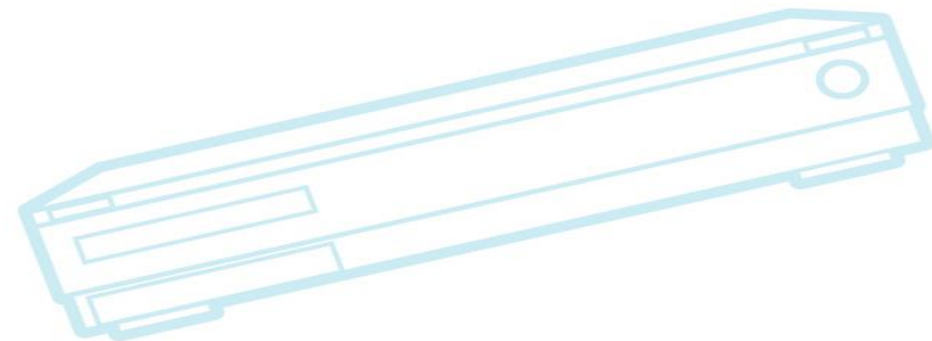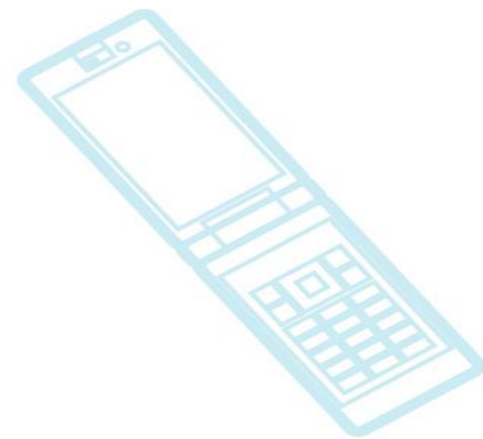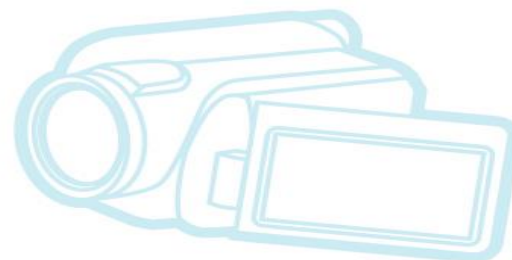
Conclusions

- Overall – we're doing very well
  - Embedded Linux is widely deployed and functional (billions of devices)
- Core kernel systems are in place to support embedded
  - But new hardware keeps being made
  - We'll always have things to write and upstream

- What do you think is missing to support embedded development?

Thanks!